RADC-TR-72-36
Final Technical Report
January 1972

SOLID FUEL-GASEOUS OXYGEN REACTION TECHNIQUES FOR PRODUCING HIGH ALTITUDE BARIUM VAPOR CLOUDS

Space Data Corporation

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 1057

Rome Air Development Center
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Solid Fuel - Gaseous Oxygen Reaction Techniques for Producing High Altitude Barium Vapor Clouds.

Final Report 15 April 1970 - 30 November 1971

Edward F. Allen, Jr.
Philip E. Beaudoin

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Program is to develop superior techniques for producing barium vapor clouds at high altitudes using sounding rockets. Several possible vapor production reactions are considered and thermochemical computations are performed comparing achievable efficiencies of yielding free barium at high temperatures. Several prime candidate reactions are evaluated for safety in use and practicality in reactor design. A reactor has been designed for future implementation. Thermochemical computations, ground test results and preliminary flight test observations indicate a large increase in vaporization efficiency over previously used reactions.

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer

RADC Contract Engineer

SOLID FUEL-GASEOUS OXYGEN REACTION TECHNIQUES FOR PRODUCING HIGH ALTITUDE BARIUM VAPOR CLOUDS

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FOREWORD

This is a Final Report covering the period 15 April 1970 to 30 November 1971. Technical Reports RADC-TR-71-32[1] and RADC-TR-71-228[2] covering the periods 15 April 1970 to 1 November 1970 and 15 April 1970 to 7 April 1971 respectively are hereby referenced.

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SUMMARY

A program has been conducted to develop a superior technique for producing barium vapor clouds at high altitudes using sounding rockets.

Several possible vapor production reactions have been considered and thermochemical computations have been performed to compare achievable efficiencies of some combustion reactions yielding free barium at high temperatures. The reactions considered were compared with the n Ba + CuO reaction currently in use for this purpose.

Besides vapor production efficiency, the candidate reactions have also been considered from aspects of safety and practicality of reactor design.

Two reactions have been selected:

$$n\,Ba + 1/2\,O_2 \longrightarrow BaO + (n-1)\,Ba \qquad (1)$$

and

$$n\,Ba + Be + 1/2\,O_2 \longrightarrow BeO + n\,Ba \rightleftharpoons BaO + Be + (n-1)\,Ba \qquad (2)$$

Thermochemical analyses have been performed on these two reactions to determine the optimum value of n, combustion temperature as a function of n, equilibrium constant for the oxygen competition in reaction (2) and vaporization efficiency as a function of n.

Two reactor designs have been completed and ground and flight tested. The series reactor (SDC 428-12) incorporates two canisters separated by two burst discs. The combustion canister contains the barium and beryllium while an accumulator canister contains the oxygen. The parallel reactor incorporates an

inner canister of oxygen surrounded by an outer canister containing barium. Linear shaped charge is used to cut the inner oxygen canister thus allowing the O_2 and Ba to mix.

Ground tests were conducted on both reactions using both the series and parallel reactors as well as a sub-scale parallel reactor. These ground tests indicated both reactions to be more energetic than the n Ba + CuO reaction with greater loadings of non-reacted vaporizable barium.

A series reactor containing 1 kg of 3Ba + Be + 1/2 O_2 was successfully flight tested (Tangerine) indicating greater electron density than given by a 2 kg charge of 1.7 Ba + CuO released from the same rocket[8].

A parallel reactor (SDC 477-10) containing 16 kg of 3Ba + 1/2 O_2 was flight tested and compared to a 16 kg charge of 2.5Ba + CuO + 1.8% Ba $(N_3)_2$ carried on the same rocket (Dardabasi). The electron density from the 3Ba + 1/2 O_2 reaction was less then from the 2.5Ba + CuO + 1.8% Ba $(N_3)_2$ reaction due to inadequate mixing of the Ba and O_2.

Thermochemical computations, ground test results of both reactors, and flight test results of the series reactor indicate that a 3.5 fold improvement in vaporization efficiency can be achieved from the 3Ba + 1/2 O_2 system with proper mixing of the Ba and O_2.

Proper mixing of the Ba and O_2 can be accomplished by modification of the existing reactor designs.

1. INTRODUCTION

Space Data Corporation has been working since 15 April 1970 to devise and develop a barium vapor deployment technique having significantly greater vaporization efficiency than the n Ba + CuO reaction currently in use for Project Secede.

The current scientific objectives of Project Secede require placement of barium ion clouds in the ionosphere. Thus far, sounding rockets have been used to carry chemical payloads with as much as 352 kg of Ba + CuO thermite to the required release altitudes[3].

Estimates of barium vapor yield from various versions of the n Ba + CuO reaction have been made and have ranged between approximately 1% and 10% [4][5][6][7] of the total chemical weight which corresponds to approximately 0.5% to 5% of the achievable gross payload weight assuming a nominal 50% efficiency in payload packaging.

The primary goal of this program has been to develop a vaporization technique capable of producing significantly more vapor per pound of payload than has thus far been produced. With increased vaporization efficiency of three or more, smaller payloads and correspondingly smaller and less expensive vehicles will be required to achieve the SECEDE scientific objectives.

In addition to having the capacity for producing greater vaporization efficiency, it is necessary that the new technique be capable of implementation on a sounding rocket payload at a reasonable cost, and offer no undue handling hazards.

This report describes the design, ground tests and flight test of the parallel reactor using the $3Ba + 1/2\ O_2$ formulation. Technical Reports RADC-TR-71-32[1] and 228[2] describe the thermochemical analysis of candidate formulations, and design, ground and flight test of a series reactor using the $3Ba + Be + 1/2\ O_2$ formulation.

2. THERMOCHEMISTRY

Gaseous and liquid oxidizers such as O_2, Cl_2, F_2, and ClF_3 were considered. Thermodynamic comparison of these oxidizers are shown in Table 1. Gaseous oxygen was chosen for this program over the halogens as it is considered safer to handle and provides a more predictable system to analyze thermochemically.

A method of thermochemical comparison was devised by assuming two sequential processes: The first (1) is adiabatic combustion at constant pressure with only liquid products permitted. The second (2) is adiabatic vaporization of liquid barium upon release into the vacuum.

This method was used to compare the two candidate reactions:

$$n\,Ba + 1/2\,O_2 \longrightarrow BaO + (n-1)\,Ba$$

$$n\,Ba + Be + 1/2\,O_2 \longrightarrow BeO + n\,Ba \rightleftharpoons BaO + Be + (n-1)\,Ba$$

with the standard reaction:

$$n\,Ba + CuO \longrightarrow BaO + Cu + (n-1)\,Ba$$

Ground tests have verified the results of the thermochemical analysis.

The results of the thermochemical analysis are shown in Figure 1.0. It is concluded from the analysis that the Ba + O_2 systems will provide an increased barium vapor yield of 3.5 over the n Ba + CuO systems.

Although the n Ba + Be + 1/2 O_2 system provides a slightly better yield then the n Ba + 1/2 O_2 system it is felt this slight improvement does not overshadow the added safety considerations and the uncertainty of the reaction products.

TABLE I

THERMODYNAMIC COMPARISONS OF HALOGEN AND OXYGEN REACTIONS WITH BARIUM

Reaction	Combustion Temperature °K	Weight Percentage Non-Reacting Ba
$1.7\ Ba + CuO \rightarrow BaO + Cu + 0.7\ Ba$	3060	31%
$4\ Ba + 1/2\ O_2 \rightarrow BaO + 2\ Ba$	3060	73%
$7\ Ba + Cl_2 \rightarrow BaCl_2 + 6Ba$	3060	80%
$11\ Ba + F_2 \rightarrow BaF_2 + 10\ Ba$	3060	89%
$36\ Ba + 2ClF_3 \rightarrow BaCl_2 + 3BaF_2 + 32\ Ba$	3060	85%

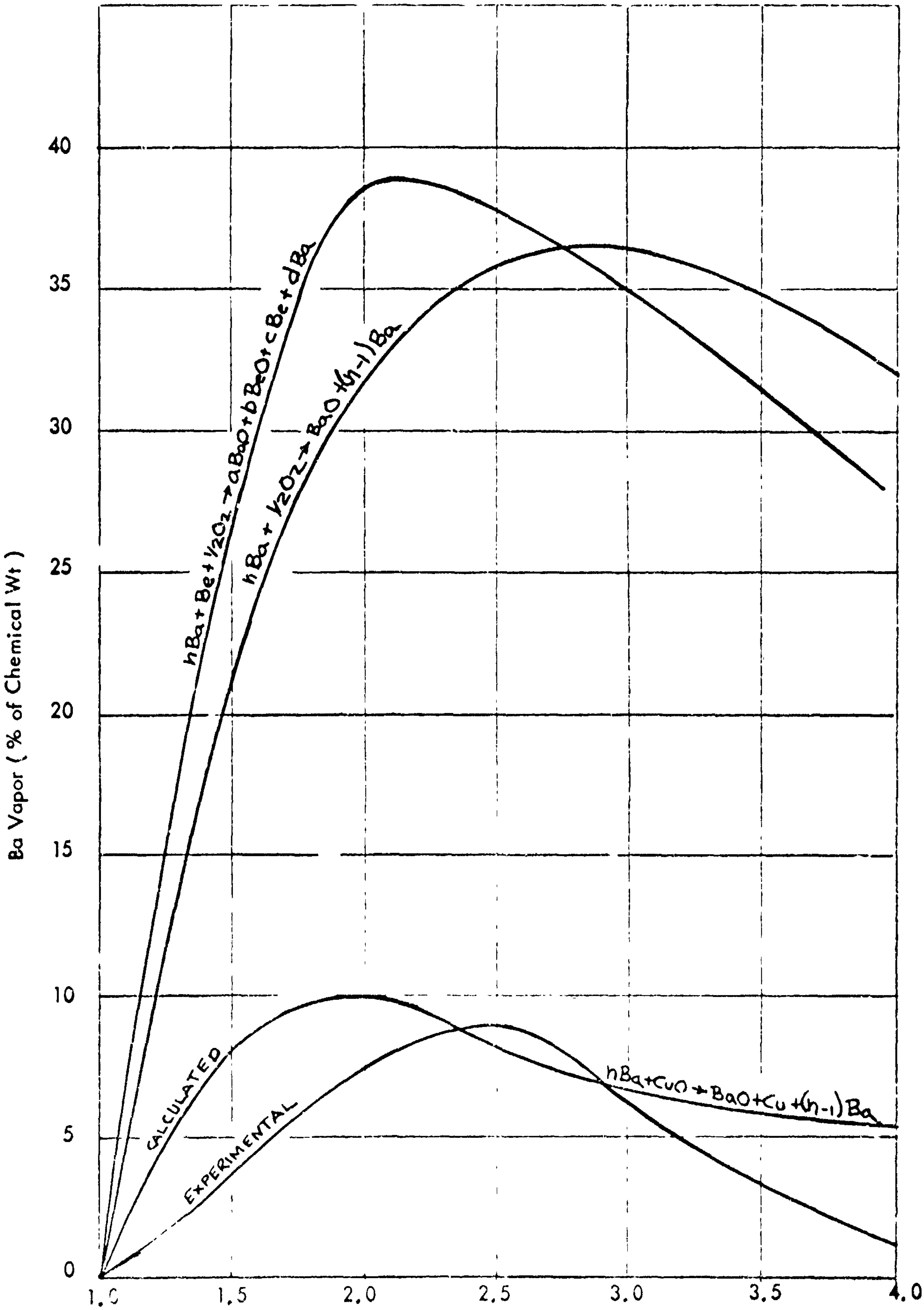

FIGURE 1 WEIGHT PERCENT BARIUM VAPOR VERSUS n

3. REACTORS

Two reactors were developed, ground tested and flight tested.

3.1 Series Reactor

A series reactor, as shown in Figure 2.0 was utilized for flight test Tangerine.

The series reactor consists of a steel canister containing the barium and two rupture disc sealed exhaust ports. A separate steel accumulator contains the oxygen. The canister and the accumulator are connected by a steel union containing two each rupture disc seals.

The accumulator contains a pyrotechnic gas generator driven piston.

Upon initiation the piston forces the oxygen through the two rupture disc seals and into the barium canister. Immediate combustion occurs and the resulting pressure and temperature ruptures the exhaust port seals and venting follows.

The barium canister has been designed with sufficient strength to contain the combustion reactions in a closed can configuration. Ground tests have verified this design.

3.2 Parallel Reactor

A paralleled reactor as shown in Figure 3.0, was designed and utilized for flight test Dardabrsl.

This reactor consists of an inner cylinder containing oxygen

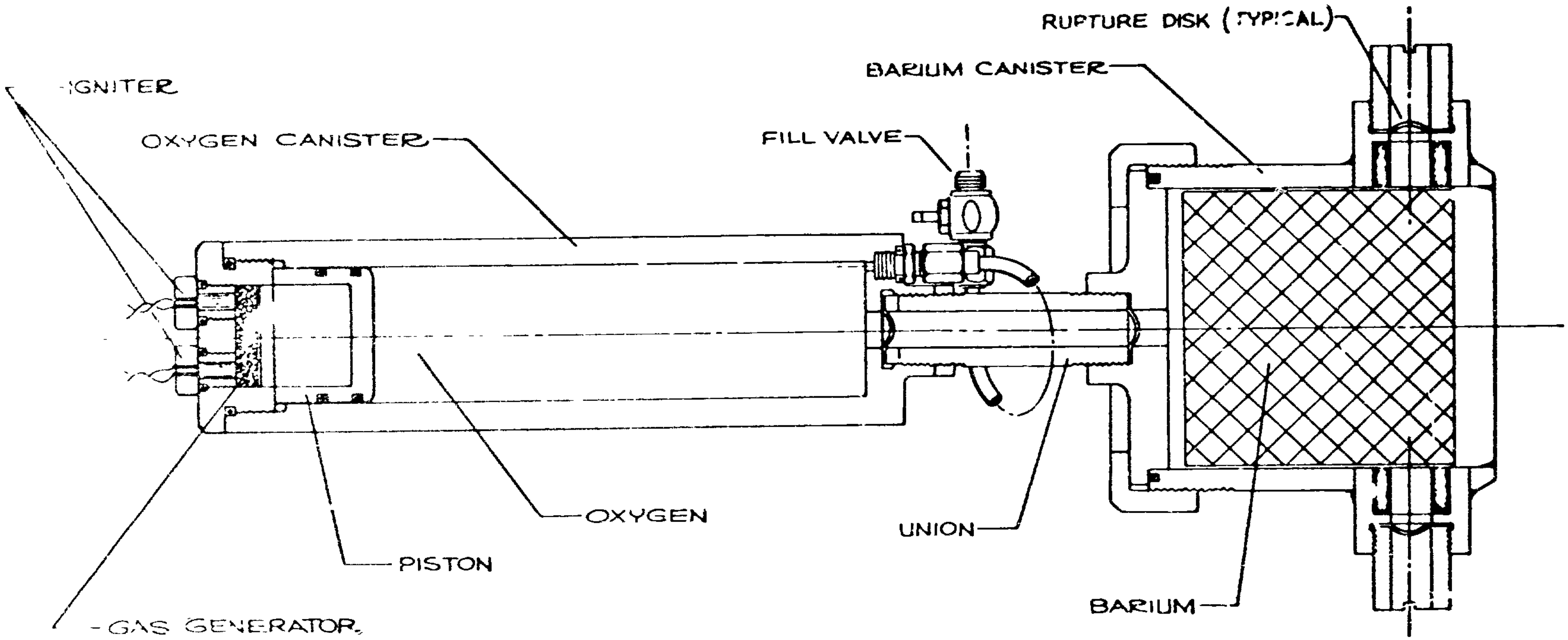

FIGURE 2 SERIES REACTOR

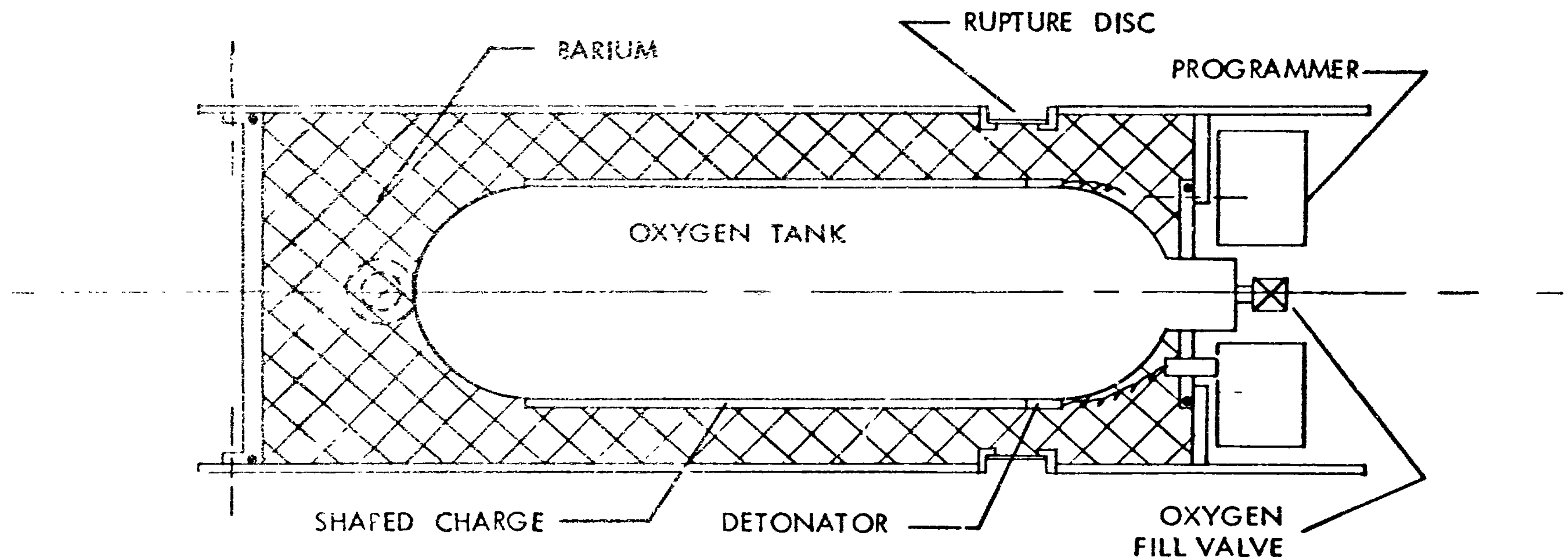

FIGURE 3 PARALLEL REACTOR

surrounded by the barium metal and all enclosed in an outer steel flight envelope. The outer envelope contains four exhaust ports with protective seals.

The oxygen is released into the barium metal by cutting open the oxygen cylinder with linear shaped charge. A programmer consisting of batteries, arming and safing devices, and a timing device is provided to initiate the shaped charge.

The parallel reactor design stresses safety and ease of handling. At no time is it necessary to handle the barium metal in combination with an oxidizer, i.e., CuO. As a result the loading of the barium metal into the canister is simplified and safer. Also, the production operations of mixing the barium metal and metal oxidizer are eliminated.

The oxygen cylinder is filled at the launch site prior to installation of the payload onto the rocket. Therefore, shipping of the reactor is simplified.

The Dardabasi module contained 15,400 grams of barium and 600 grams of oxygen. The module including event programmer was 9 inches in diameter, 27 inches long and weighed 86.3 pounds.

A full scale ground test was performed on the parallel reactor prior to Dardabasi. Structural integrity and adequate mixing of the barium and oxygen was verified.

4. FLIGHT TEST - TANGERINE

A payload consisting of a standard 2 kg 1.7 Ba + CuO release and a series reactor 1 kg 3Ba + Be + $0.5O_2$ release was flown at Eglin Air Force Base in October 1970 aboard a Nike Hydac vehicle.

The intent was that both releases would occur at 185 km but the trajectory was higher than planned and both payloads were released above 200 kilometers. As a result the peak electron densities were substantially lower than expected and direct backscatter from the clouds was not observed. The clouds were detected, however, via forward scatter paths involving ionospheric reflections. The absence of direct backscatter echoes and the presence of forward scatter echoes has been used to place upper and lower bounds on the peak electron density in both clouds. It is concluded that the new mix produced a cloud having, at worst, the same peak electron density as that expected from the standard mix and, at best, 6 times as great[8].

5. FLIGHT TEST - DARDABASI

A payload consisting of a standard 16 kg 2.5 Ba + CuO + Ba (N_3) (1.8% by weight) release and a parallel reactor 16 kg 3Ba + 0.5O_2 release was flown from Barking Sands on 7 November 1971 aboard a Terrier Tomahawk vehicle.

A summary of the flight is given in Table 2.

The expected approximate 3.5 fold improvement of the n Ba + O_2 system over the n Ba + CuO system was not realized from Dardabasi. The results from the Raytheon[9] data shown that the 3Ba + 1/2 O_2 system produced on electron density equivalent to 59% of that produced by the 2.5 Ba + CuO + Ba $(N_3)_2$ (1.8% by Wt.) standard system.

Post flight analysis indicate the following possible reasons for the reduced electron yield:

(1) Inadequate mixing of the barium and oxygen

(2) Reduced net oxygen due to leakage prior to or during flight.

Leakage of oxygen prior to launch is discounted as the net oxygen was monitored for four days prior to launch with no charge in net detected. Leakage of oxygen during flight and prior to release is unlikely due to the integrity of the system as determined by the ground checks prior to launch.

Inadequate mixing of the barium and oxygen is the probable cause of the low yield. Two lengths of linear shaped charge were used to cut the oxygen tank. Each length had its own detonator and the lengths were

TABLE 2 FLIGHT TEST SUMMARY - DARDABASI

Launch Site:	Barking Sands, Kauai, Hawaii
Launch Date:	7 November 1971
Launch Time:	0426 Z
Vehicle:	Terrier Tomahawk
Payload Gross Wt.	250 lbs.
Launch QE:	78°
Peak Altitude:	909,137 Ft.
Peak Range (Horizontal):	105.51 NM
Impact Range:	UNK - LOT
Impact Azimuth:	UNK - LOT

DARDABASI I (2.5 Ba + CuO + 1.8% Ba $(N_3)_2$)

Chemical Weight	16 kg
Release Time	129.8 sec.
Release Altitude	[illegible]3.2 km
Release Range (Horizontal)	89.9 km

DARDABASI II (3Ba + 1/2 O_2)

Chemical Weight	16,000 gm
Barium Weight	15,401 gm
Oxygen Weight	599 gm
Release Time	394.6 sec.
Release Altitude	197.9 km
Release Range (Horizontal)	295.48 km

placed opposite each other and ran the overall length of the cylindrical portion of the oxygen cylinder. If only one length of shaped charge detonated less efficient mixing would occur. It is possible that the basic design of releasing the oxygen into the barium by the shaped charge technique is inefficient although the full scale ground test did not so indicate.

6. CONCLUSIONS

It is concluded that:

(1) The O_2 system can provide a 3.5 fold improvement over the n Ba + CuO system.

Flight test Tangerine indicated the n Ba + Be + 1/2 O_2 reaction utilizing the series reactor to be at worst equal to and at best a six (6) fold improvement over the n Ba + CuO system.

(3) The low yield of flight test Dardabasi resulted from inadequate Ba + O_2 mixing in the parallel reactor.

7. RECOMMENDATIONS

Thermochemical analysis and ground tests have verified that the n Ba $\pm$ O_2 system can provide an approximate 3.5 fold improvement over the n Ba + CuO system.

Flight tests to date have not conclusively verified a 3.5 fold improvement but indicate that with adequate Ba - O_2 mixing this improvement is possible.

Attempts to achieve a significant improvement with other chemistries have provided only a slight improvement i.e., 1.54[9].

It is therefore, recommended that development of the n Ba + 1/2 O_2 system be continued to produce a reactor to provide adequate mixing of the barium-oxygen.

Space Data Corporation proposes the following approach to solving the mixing problem:

(1) Develop the series reactor concept into a full scale (16 kg) flight weight reactor.

(2) Redesign the parallel reactor oxygen cylinder and cutting system to provide more rapid oxygen release.

(3) Flight test each system inconjunction with a n Ba + CuO system utilizing a command release system as done on Dardabasi.

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